Liquid Methane/Liquid Oxygen Cryogenic Monopropellant and Explosive Literature

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Liquid methane/liquid oxygen (MOX) solutions have received some, but limited, attention in the literature as a propellant or as an explosive. The acronym MOX is used to refer to cryogenic monopropellant mixtures of liquid methane or liquefied natural gas and liquid oxygen. Interest in reduced-toxicity, high-performance propellants with the potential for in situ production in extraterrestrial environments has prompted a new look into the potential of a MOX propulsion system and its explosion hazards.

A literature review was performed and consolidated at NASA Johnson Space Center's White Sands Test Facility to provide a single source of information for references to MOX properties, hazards, critical diameter considerations, burning rates, combustion instability, trinitrotoluene (TNT) equivalency, shock sensitivity, and vibration tolerance, some related to spacecraft environments and others to Earth-based explosive applications. The review contains information found on MOX monopropellant evaluation and feasibility studies, detonation and burning characteristics, explosive systems, ignition and combustion characteristics, patents, and methods for preparation and storage. The review also includes some advantages and disadvantages of MOX monopropellant versus liquid oxygen (LOX)/methane bipropellant and storage systems.

LOX/liquid methane has been examined by a number of investigators since the 1950s as a monopropellant for jet or spacecraft engines, and as a brisant (powerful and shattering) explosive. Recent testing raised concerns over the potential formation of MOX with explosive consequences. The potential for cold flows (flowing of propellants under non-ignition conditions), or inadvertent mixing of LOX and liquid methane to form a potentially detonable mixture, demonstrated the need for a better understanding of MOX. Oxygen and methane form a single-phase liquid at temperatures above the freezing point of methane; at much lower temperatures, it is still possible to prepare very concentrated single-phase mixtures. A methane-oxygen phase diagram is shown in figure 1. Research has shown that the most brisant mixture was the stoichiometric mixture (33.33 mole percent methane and 66.67 mole percent oxygen). The phase diagram also illustrates the wide temperature range over which MOX is a liquid at that composition.

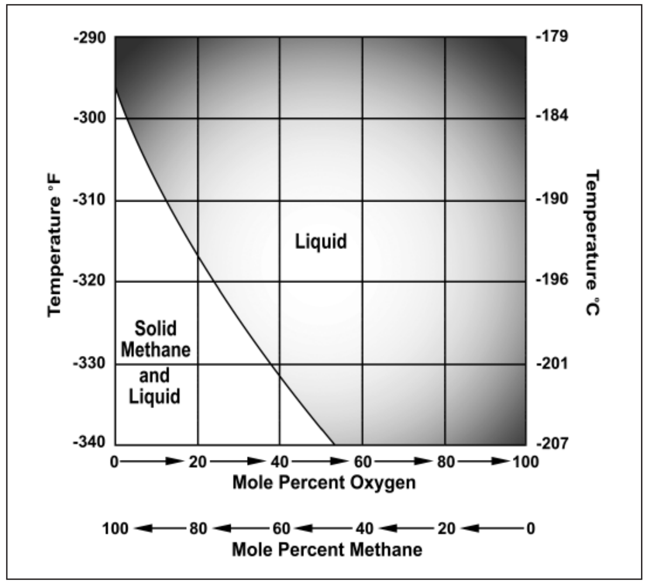

Fig. 1. *Methane-liquid oxygen phase diagram.*

This work presents a summary of literature relevant to MOX and LOX/liquid methane monopropellant and explosive properties and testing. MOX made with liquefied natural gas (LNG) and LOX/LNG monopropellant and explosive are included. Patent literature was included because of the limited amount of technical publications and for the reader to appreciate the claims related to propulsion and explosive applications. In addition, some of the patents provide methods for the preparation and storage of MOX, which may be useful if this fluid gains interest in use.

Figure 2 depicts the approximate number of MOX-related publications and patents found in this survey. The most concentrated interest in MOX began around 1957 and peaked in 1966. There were limited publications between 1970 and 1978, and only one found in the 1980s. Sporadic publications and patents, including this review, appeared from 1994 to the present.

While an extensive variety of LOX/hydrocarbon bipropellant combinations, including LOX/methane, have

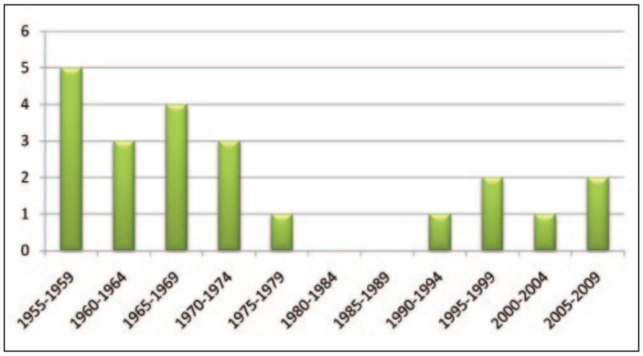

Fig. 2. *Number of liquid methane/liquid oxygen-related papers vs. year of publication.*

been successfully used for many years in spacecraft engine applications, monopropellant blends have experienced significantly fewer applications, sometimes with explosive results. The bulk of collective experience with LOX/hydrocarbon mixtures is that shock sensitive mixtures are produced when LOX and the hydrocarbon are mixed in ratios near stoichiometric. Not only has MOX been proposed and evaluated as a cryogenic monopropellant, it has also been patented as an explosive for cracking rock in mining applications.

The literature appears limited to experimental work and calculations; no reports of known functioning spacecraft engines using MOX were found. Utility as a monopropellant is limited by the potential for detonations (including deflagration-to-detonation transition back through feed lines from a combustion chamber to the fuel tank), physical considerations such as phase changes, and non-Earth cryogenic storage challenges. However, the potential advantages of MOX as a monopropellant—with respect to the relative simplicity of high performance monopropellant engines and loss of weight penalty due to elimination of associated hardware including tanks, supply lines, and valves as compared to bipropellant engines—should be kept in mind. As LOX/liquid methane bipropellant systems continue to garner interest and increased use, and if in situ propellant production in extraterrestrial environments transitions from concept to reality, the potential for MOX monopropellant systems should also be considered.